Tomato

Steven A. Sargent[1] and Celso L. Moretti[2]
[1]Horticultural Sciences Department, University of Florida, Gainesville, FL
[2]EMBRAPA, National Vegetable Crop Research Center, Brasilia, Brazil

Scientific Name and Introduction: Tomato (*Lycopersicum esculentum*) is a warm-season crop with origins in elevated regions of Peru and Ecuador. A member of the Solanaceae family, tomato is the second most produced vegetable in the U.S., behind potato. Domestic production is year-round, although Winter and Spring imports from Mexico are having an increased impact. The majority of tomatoes are grown in the field; however, the use of protected culture is on the rise around the world. Dominant suppliers of greenhouse-grown tomatoes to U.S. markets are Holland, Spain, Israel and Canada. The round, red-flesh tomato predominates in the fresh-market, but both red and yellow-fleshed round, plum (roma), cluster, cherry, grape and mini-pear types are also available.

Quality Characteristics and Criteria: High quality fruit have a firm, turgid appearance, uniform and shiny color, without signs of mechanical injuries, shriveling or decay. Principle causes for postharvest losses are decay, external damages incurred during harvest and handling, and harvest at an improper maturity stage.

Horticultural Maturity Indices: Depending on the market and production area, tomatoes are harvested at stages of maturity ranging from physiological maturity (mature-green stage) through full-ripe. Immature tomatoes are available for certain regional dishes. It is difficult to accurately determine the completion of physiological maturity. Depending on the growing area and time of harvest, the percent of immature tomatoes (M-1) in lots of green-harvested tomatoes can range from 20 to 80% (Sargent and VanSickle, 1996) (see below). Tomatoes harvested at the mature-green stage (M-3 or M-4) will ripen to high quality if handled properly (Maul et al, 1998). Tomatoes harvested at the M-2 stage will ripen to moderate quality, while those harvested at M-1 stage will not ripen to acceptable levels of quality.

Maturity Stage[1]	**Internal Appearance (equatorial section)**
M-1	Seeds immature (white) and can be cut when the tomato is sliced; no gel in the locule.
M-2	Seeds mature (tan); gel formation in at least two locules.
M-3	Seeds pushed aside when tomato sliced; all locules have gel; internal color is still green.
M-4	Appearance of red color in gel and pericarp tissue.

[1]Adapted from Kader and Morris (1976).

Ripeness stages are defined according to the following standards for red-fleshed tomatoes (USDA, 1991):

Ripeness Stage[1]	**External Color**
(1) Green	Fruit surface is completely green; the shade of green may vary from light to dark.
(2) Breaker	there is a definite break in color from green to tannish-yellow, pink or red on not more than 10% of the surface.
(3) Turning	10% to 30% of the surface is not green; in the aggregate, shows a definite change from green to tannish-yellow, pink, red, or a combination thereof.
(4) Pink	30% to 60% of the surface is not green; in the aggregate, shows pink or red color.
(5) Light red	60% to 90% of the surface is not green; in the aggregate, shows pinkish-red or red.
(6) Red	More than 90% of the surface is not green; in the aggregate, shows red color.

[1]Tomato color standards USDA Visual Aid TM- L-1 consists of a chart containing twelve color photographs illustrating the color classification requirements and may be purchased from The John Henry Company, 5800 W. Grand River Avenue, P.O. Box 17099, Lansing, MI 48901-7099.

Grades, Sizes and Packaging: Grades for field-grown tomatoes include U.S. No. 1, No. 2, U.S. Combination, and No. 3, with established tolerances set for defects at shipping point and en route or at destination (USDA, 1991). Fruit within a grade should have similar varietal characteristics, be uniformly mature, not overripe or soft, be clean, well developed, fairly well formed, fairly smooth, and have uniform color. Fruit should be free from decay, freezing injury, sunscald, and damage due to bruising, discoloration, sunken scars, cuts and broken skins, puffiness, catfaces, other scars, radial or concentric growth cracks, and hail/insect injury.

Tomatoes are rigorously sized with a 0.8 mm (1/32-in) overlap permitted between sizes, according to the following dimensions (USDA, 1991):

Size	**Minimum Diameter [1]**	**Maximum Diameter[2]**
Small	5.40 cm (2 4/32 in)	5.79 cm (2 9/32 in)
Medium	5.72 cm (2 8/32 in)	6.43 cm (2 17/32 in)
Large	6.35 cm (2 16/32 in)	7.06 cm (2 25/32 in)
Extra Large	7.00 cm (2 24/32 in)	

[1] Will not pass through a round opening of the designated diameter when tomato is placed with the greatest transverse diameter across the opening.
[2] Will pass through a round opening of the designated diameter in any position.

Field-grown tomatoes are typically packed in lidded, 11.4 kg (25 lb) cartons, 30 x 40 x 24 cm (12 x 16 x 9.5 in) (W x L x H), that stack 10 cartons per layer on a 100 x 120 cm (40 x 48 in) pallet. Grades for greenhouse tomatoes include U.S. No. 1, No. 2, and Unclassified (USDA, 1966). Ripeness stages and defects are similar to field-grown tomatoes. These fruit are sized as follows:

Size	**Weight**
Small	< 99.4 g (3.5 oz)
Medium	99.4 to 256 g (3.5 to 9 oz)
Large	> 256 g (9 oz)

Greenhouse-grown tomatoes are generally harvested at turning stage or later and packed according to ripeness and size (count) in single- or double-layer cartons, with or without bottom trays. Cluster tomatoes are usually picked when the least mature tomato begins to show red color. Uniformity of fruit color, stem freshness and fruit attachment to the stem are important quality characteristics for this tomato type. Cluster tomatoes are usually packed in single-layer cartons, sometimes in netted bags. Foam bottom pads may be inserted to reduce abrasion and bruising.

Although there are currently no U.S. grade standards for other types of tomatoes, they are all typically harvested once ripening has started and are sorted by defect and color. Roma-type tomatoes are normally packed in 11.4 kg (25 lb) cartons by color, while cherry, grape and mini-pear tomatoes are packed in 227 to 454 g (8 to 16 oz) baskets or hinged, clamshell containers and placed in larger, master cartons to facilitate palletizing.

Pre-Cooling Conditions: Following commercial packing, tomatoes are routinely palletized and cooled to 20 °C (68 °F) for ripening or to 12 °C (53.6 °F) for storage. While room-cooling is common, forced-air cooling is more uniform and produces a better quality fruit. Packed, palletized tomatoes with pulp temperature of 28 °C (82.4 °F) actually increased 2 °C (3.6 °F) immediately after being stored at 20 °C (68

°F), and only cooled to 23 °C (73.4 °F) after 24 h using room-cooling (Brecht, 1996). However, with forced-air cooling, tomatoes cooled to 20 °C (68 °F) in 2.5 h and ripened more uniformly throughout the pallet than those room-cooled.

Optimum Storage Conditions: Optimal storage temperatures depend on the maturity stage of the tomatoes. Ideal conditions for ripening are 19 to 21 °C (66 to 70 °F) with 90 to 95% RH. Storage > 27 °C (81 °F) reduces intensity of red color, while storage < 13 °C (55.4 °F) retards ripening and can lead to development of chilling injury, particularly in tomatoes at the mature-green stage. Red tomatoes can be stored at 7 °C (44.6 °F) for a couple of days, although tomatoes stored at 10 °C (50 °F) were rated lower in flavor and aroma than those held at 13 °C (55.4 °F) (Maul et al, 2000).

Controlled Atmosphere (CA) Considerations: Tomatoes can be stored under CA to extend product quality (see below). The exact combination of CO_2 and O_2 varies among maturity stages and cultivars; but a satisfactory CA is 3% O_2 + 2% CO_2 (Wills et al., 1998). Storage under CA delays quality loss as measured by several factors, such as lycopene synthesis and sugar and chlorophyll degradation (Goodenough and Thomas, 1980; Nakhasi et al., 1991). Storage in 3% O_2 + 97% N_2 extended postharvest-life of mature-green tomatoes for 6 weeks at 13 °C (55.4 °F) without the development of off-flavors (Parsons et al., 1970). Storage under CA may reduce development of undesirable symptoms due to mechanical injury (Kader, 1986). However, Moretti et al. (1999) observed that CA storage did not alleviate development of internal bruising (disruption of locular gel ripening) following impacts of tomato fruits.

CA Storage Conditions:[1]

Ripeness Stage	**Temperature**	**O_2(%)**	**CO_2(%)**	**Benefit**
Mature green	12 to 20 °C	3 to 5	2 to 3	slight
Red	10 to 15 °C	3 to 5	3 to 5	moderate

[1]From Saltveit (1997).

Retail Outlet Display Considerations: Tomatoes are normally displayed at the retail level in single-layer, corrugated cartons or in plastic clamshell containers at about 20 °C (68 °F). Grading, sizing, and packing fruit adds value and convenience to the final product. An important issue in the marketing of high-quality tomatoes is uniformity of size, grade, firmness and color. Consumers tend to avoid packages of fruit with different colors, decay or external blemishes. Some distributors also offer tomatoes in bulk containers, giving the consumer the option to choose among different maturities, sizes and types of tomatoes. However, since tomato fruits are sensitive to compression stresses, care must be taken to avoid overloading the display.

Chilling Sensitivity: Tomato fruit are chilling sensitive and the recommended storage temperature varies with the maturity stage. Mature-green fruit will ripen normally at 13 to 21 °C (55 to 70 °F). On the other hand, ripe tomato fruits can be stored at 10 °C (50 °F), without visible symptoms of chilling injury, although flavor and aroma was negatively affected (Maul et al., 2000). Visual symptoms of chilling injury include pitting, non-uniform ripening and storage decays (see "Postharvest Pathology" section) (Wills et al., 1998).

Ethylene Production and Sensitivity: Tomato fruit produce moderate amounts of ethylene at 1 to 10 µL kg^{-1} h^{-1} at 20 °C (68 °F) (Kader, 1992) and are sensitive to ethylene exposure. As little as 0.5 µL L^{-1} ethylene is sufficient to trigger ripening and other associated metabolic processes (Abeles, et al., 1992). For commercial ripening, green tomatoes should be held at 20 to 21 °C (50 to 52 °F) with 90% RH and 50 µL L^{-1} ethylene; this will promote uniform ripening. Upon reaching breaker stage, tomatoes produce sufficient ethylene and no longer require gassing. Highest quality tomatoes are those reaching the breaker stage within 3 days of ethylene exposure. These fruit were harvested at the mature green stage and will ripen with quality similar to tomatoes harvested at the breaker or later (Maul, et al, 1998).

Respiration Rate: Tomatoes are climacteric and show a pronounced increase in respiration during ripening. The intensity and duration of the climacteric varies among fruit species (Wills et al., 1998). Respiration also varies with temperatures and atmospheric composition.

Temperature	Air[1]	3% O_2 /97% N_2[2]
	(mg CO_2 kg^{-1} h^{-1})	
10 °C	13 to 16	6
15 °C	16 to 28	-
20 °C	28 to 41	12
25 °C	35 to 51	-

[1]Data from Sholz et al. (1963). Storage at 10 °C (50 °F) recommended *only* for red-ripe tomatoes.
[2]Data from Robinson et al. (1975). To get mL kg^{-1} h^{-1}, divide the mg kg^{-1} h^{-1} rate by 2.0 at 0 °C (32 °F), 1.9 at 10 °C (50 °F), and 1.8 at 20 °C (68 °F). To calculate heat production, multiply mg kg^{-1} h^{-1} by 220 to get BTU per ton per day or by 61 to get kcal per metric ton per day.

Physiological Disorders: Blotchy ripening is a physiological disorder characterized by the randomized development of green or green-yellowish areas on the surface of red tomato fruit. Apparently, the development of this disorder is related to the availability of potassium and inorganic nitrogen in the soil system. Areas showing blotchy ripening have less organic acids, SSC, and starch (Moretti et al., 2000).

Sunburn is associated with excessive exposure to the sunlight and the resultant elevated tissue temperature during fruit development, disrupting lycopene synthesis and resulting in the appearance of yellow areas in the affected tissues that remain during the ripening process.

Blossom-end rot is a physiological disorder involving a calcium deficiency that is either due to poor uptake or translocation into the fruit. Symptoms begin in the green fruit as a small discoloration at the blossom end that increases in size and becomes dry and dark-brown. Occurrence increases dramatically when calcium levels in the soil system drop below 0.08% (Moretti et al., 2000). Eventually, secondary decay organisms colonize weakened tissues.

Graywall is noticeable as necrotic vascular tissue in the pericarp fruit wall (Jones et al., 1999). It begins developing at the green stage and has been associated with marginal growing conditions such as cool weather, low light levels, poor nutrition, saturated soils, tobacco mosaic virus, and bacteria; however, the cause is still undetermined. Graywall can be a serious disorder in both field and greenhouse production systems.

Irregular ripening is characterized by the appearance of non-uniform ripening and white internal tissue. It has been associated with the feeding of sweetpotato whitefly (*Bemisia argentifolii*) on tomato fruit (Hanif-Khan et al., 1997).

Internal bruising is recognized by the appearance of yellow to green locular gel in ripe tomatoes. It is caused by an impairment of normal ripening of the locular gel following a physical impact at the green or breaker stage of ripeness (MacLeod et al, 1976). Fruit with internal bruising show significant reductions in Vitamin C content, TA, consistency and total carotenoids (Moretti et al., 1998). Besides altering quality attributes, internal bruising also affects tomato fruit flavor (Moretti et al., 2002). Breaker-stage tomatoes are more sensitive to internal bruising than those handled at the green stage (Sargent et al, 1992).

Postharvest Pathology: Tomatoes are susceptible to numerous fruit decays, from the field through postharvest handling. Postharvest decays often develop in wounds, bruised tissue and during fruit softening. Sound tomatoes can be inoculated by plant pathogens via cross-contamination from diseased fruits, dirty harvest containers and from poorly sanitized water handling systems and packing line components. Populations of decay pathogens can be adequately controlled through a regular sanitation program in the field and during handling, packing and ripening/storage operations.

Bacterial decays include soft rots (*Bacillus* spp., *Erwinia carotovora* ssp., *Pseudomonas* spp., and *Xanthomonas campestris)*; lactic acid decay (bacterial sour rot) (*Lactobacillus* spp. and *Leuconostoc mesenteroides*) (Conn et al, 1995; Bartz et al, 1995).

Fungal decays include alternaria rot (black rot) (*Alternaria alternata*); Fusarium rot (*Fusarium* spp.); Gray Mold rot (*Botrytis cinerea*); Mucor rot (*Mucor mucedo*); Phoma rot (*Phoma* ssp.); Phomopsis rot (*Diaporthe* ssp.); Phytophthora rot (Buckeye rot) (*Phytophthora* spp.); Pleospora rot (*Pleospora herbarum; Stemphylium botryosum,*imp. stage); Rhizopus rot (*Rhizopus stolonifer*, *R. oryzae*); Ring rot (*Myrothecium roridum*); Sclerotium rot (*Sclerotium rolfsii*); Sour rot (*Geotrichum candidum*); Target spot (*Corynespora cassiicola*); Watery soft rot (*Sclerotinia minor*, *S. sclerotiorum*). Tomato spotted wilt virus induces a mottled coloration at red stage. Adapted from Jones et al. (1991) and Snowden (1992).

Quarantine Issues: Tomato fruit are a host for fruit flies, and are subject to inspection in quarantined areas. Methyl bromide has been employed for a wide range of fruits and vegetables. However, it is being phased out. Tomatoes have a phytotoxic response, characterized by delayed ripening and reduced sensitivity to exposure to ethylene (Brecht, 1994). Vapor heat and hot water treatments are effective alternatives.

Suitability as Fresh-cut Product: Despite efforts to commercialize fresh-cut tomatoes, such products are still only available in limited quantities to the food service industry, particularly fast-food restaurants and catering services. After processing, loss of the gel-like locule tissue, desiccation, water-soaking and the development of decay are the principle constraints challenging the worldwide fresh-cut industry. Crossing commercial varieties with mutants with delayed softening, and slicing less ripe tomatoes, eg., breaker stage, for subsequent application of ethylene are strategies being researched in different parts of the world to obtain a fresh-cut tomato with sufficient postharvest-life to be readily commercialized. Mature-green, sliced tomatoes ripened normally at 20 °C (68 °F) (Mencarelli and Saltveit, 1988). Sliced, red tomatoes maintained good quality for 14 days when stored in MAP at 5 °C (Hong and Gross, 2001).

Special Considerations: Ethylene used to ripen tomatoes can be catalytically generated from ethanol using commercially available units, or supplied from compressed air cylinders. Because air mixtures of 3 to 32% ethylene are explosive (Abeles et al., 1992), ethylene for ripening rooms is supplied from a compressed cylinder containing a < 3% ethylene in N_2 mixture. A metered flow of ethylene from either a catalytic unit or compressed cylinder is used to produce a diluted, active concentration of ethylene in the ripening room.

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